Naturalizing as an error-type in Biology

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Abstract: Biologists make mistakes – but they can also find them and remedy them. I survey a series of cases where idealizations and assumptions about normality have shaped common erroneous biological concepts: male and female; developmental abnormalities; competition in evolution; and laws of nature. Such scientific interpretations of nature can have profound social consequences. Identifying such recurring errors thematically, however, can guide analysis that improves the reliability of scientific claims. Here, I profile naturalizing as one such error type and map the prospective solutions.
Keywords: error types; naturalizing; male and female; developmental abnormalities; competition in evolution; laws of nature

Naturalizar como um tipo de erro em Biologia

Resumo: Biólogos cometem erros – mas eles também podem encontrá-los e consertá-los. Eu relato uma série de casos nos quais idealizações e pressuposições sobre normalidade conformaram conceitos biológicos comuns errados: macho e fêmea; anormalidades de desenvolvimento; competição na evolução; e leis da natureza. Tais interpretações científicas da natureza podem ter conseqüências sociais profundas. Identificar tais erros recorrentes tematicamente, contudo, pode guiar uma análise que melhore a confiabilidade das asserções científicas. Aqui eu traço um perfil do naturalizar como sendo um desses tipos de erro e mapeio soluções prospectivas.
Palavras-chave: tipos de erros; naturalizar; macho e fêmea; anomalias de desenvolvimento; competição na evolução; leis da natureza.

1 INTRODUCTION

What seems more natural than boy and girl, man and woman, male and female? That, indeed, I think is a problem. And I want to probe it, along with some other cases, to profile a thematic

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category of errors found especially in biology. By profiling and characterizing these errors – or this error-type – I hope to support more effective regulation of error in science. This contributes to a larger endeavor – Error Analytics – for improving scientific practice through more active, philosophically informed analysis of potential error. Understanding error types can foster greater awareness, discourse and education about methods for minimizing, alleviating or compensating for such errors.

My discussion roams broadly, addressing developmental anomalies, competition in nature and, at a more general level, laws of nature. I will begin, however, with the case of male and female.

2 MALE AND FEMALE

Conceptualizing sex as male and female seems straightforward (for all references, see Allchin, 2006a). In the standard version, females have two X-chromosomes, while males have an X and a Y. They have different gametes: one sessile, one mobile. Accordingly, it seems, male and female organisms have contrasting gonads, contrasting hormones, contrasting physiologies and contrasting secondary sex characteristics. Organs begin embryologically the same, but follow different developmental trajectories. One often hears about contrasting behaviors in evolutionary language: sperm are cheap and males are "promiscuous"; eggs are major investments and females are protective and cunning. The apparent alignment of different features through all levels of biological organization seems to confirm the two categories. An organism is either male or female. – And that is what textbooks present as biological "fact."

Of course, informed biologists know better. For example, many fish change sex: wrasses, parrot fish and groupers. In the cleaner wrasse, a community typically has one male and many females, the male releasing a pheremone that inhibits male development. When the male dies, the largest female begins changing sex in a matter of hours. By contrast, in clown fish, males may become females. Some gobies change sex multiple times. Sexed anatomies and physiologies may change. Sex can be fluid. Some organisms cannot be identified as essentially male or female.

At least such fish are male *or* female at any one time, one might contend. Yet the sorting of male and female is not always neat and simple. Properties are not so consistently aligned as the textbook dichotomy seems to indicate. Consider the *guevedoces* of the Dominican Republic, investigated in 1974 (Imperato-McGinley, Guerrero, Gautier & Peterson, 1974). A homozygous genetic condition leads to an inactive form of 5-alpha reductase. Individuals cannot convert testosterone to dihydrotestosterone, and they develop initially as females. At puberty, however, the role of testosterone becomes primary. The testes descend and penises, facial hair and other male characteristics develop. Here, no gonads change. But sexual morphology does. This is a case of intersex, not uniformly male or female.

Many types of intersexes exist. Hormonal levels, ineffective hormone receptors or alternative developmental trajectories lead to various mosaics of sexual characters. As documented nicely by Alice Dreger, human bodies may exhibit sexual anatomies in almost any combination: external genitalia, gonad position, urinary plumbing, large breasts, facial hair, hair loss, invaginations and protuberances, ejaculates and menses, and vocal timbre. These traits do not correspond uniquely to either chromosomes *or* gonad type. In other mammal species, some such "mixed" patterns are actually typical. In spotted hyenas and bush babies, male and female both exhibit penises. Male fruit bats in Malaysia have milk-producing mammary glands (Roughgarden, 2004, pp. 28, 37-38). Intersexes illustrate that the concept of male and female, construed as an unambiguous dichotomy, is problematic.

Still, male and female may seem concepts fundamental to characterizing sexual reproduction: ultimately, the union of two gametes, sperm and egg, one mobile, the other not. Yet some organisms reproduce sexually without differentiated egg and sperm. The gametes share the same form. For example: in *Chlamydomonas* or in the sea lettuce *Ulva*. There is indeed sex, but *no* male, *no* female. Accordinly, one may prefer conceiving sex as fundamentally about recombina-tion and methods for ensuring genetic variation. Here, male and females may be seen primarily as mating strains. But this leads to other problems. For example, Charles Darwin noted how some common garden flowers have different length styles and stamens. He saw this as a mechanism that promoted outcrossing.

Recombination is functionally ensured by heterostyly, not male and female. In one example, he noted three style lengths, akin to a trio of mating types. Consider also the mating system in two ant species, genus *Pogonomyrmex*. Independently of male and female, the ants have two distinct mating types. A queen that mates with a male of her own type produces more queens. To produce workers, she must mate with a male of the alternate type. Continuity of the colony requires both queens and workers, hence *both* matings. John Parker has argued that these ants thus have *four* sexes (Parker, 2004). Reproduction (assessed at the level of the colony) depends on *three* sexes–one female and *two* male. Polysexes and mating strains, too, challenge the notion of male-and-female as biologically needed, even for sexual recombination.

Sex conversions, intersexes, null sexes, mating types, and multiply morphed sexes: all challenge the concept of male-and-female. Of course, one may be tempted to dismiss these examples as *merely* exceptions. – Or rare, and *hence* insignificant. One can well imagine someone dismissing them as "unnatural". But note the irony: one might characterize as unnatural something produced by nature. The very tendency to peripheralize the "exceptional" or rare is a cognitive bias, based on familiar experience. The concept of male and female is privileged as primary, even though nature exhibits diverse patterns. The assessment is further shaped, no doubt, by cultural conventions that organize society – marriage, division of labor, toys, military service, clothing, athletics, hygiene, etc. – according to strict categories of male *or* female. But biologically, nature does not universally sort organisms into just male or female, man or woman, boy or girl.

But this is not the extent of the error. Nor the substantive error. Biologists address the less common cases when the occasion arises. Rather, the further – and far more significant – error is that in broader cultural contexts the concept of male-and-female is presumed, ironically, to be *plainly* biological. The male/female dichotomy is regarded as clear and delineated *by nature* Adam & Eve. As noted earlier, male and female categories seem – well, "natural". Intersexes, etc., are thus popularly viewed as improprieties, possibly "violations" of the natural order. They do not seem to raise awareness of nor disturb the assumptions behind the concepts. Male and female, not just gender roles, are deeply entrenched in culture through "textbook" biology. Male and female have been *naturalized*. That is, the concept shaped by bias has been inscribed in nature. Moreover, any hint of bias is eclipsed. The case of male and female illustrates nicely the problem of *naturalizing*, the error, or error-type, I am profiling here.

3 COMPETITION

Let me turn now to another case of naturalizing, where the biology has been culturally, if not scientifically, obscured: a view of nature as fundamentally competitive and selfish (for references, see Allchin, 2007a, 2007b). The view seems rooted in Darwinian concepts of evolution and natural selection, as expressed, for example, in the popular phrase "survival of the fittest". Charles Darwin noted the great potential of organisms to reproduce and of a population to increase in size. Where resources were limited, however, there would inevitably be a "struggle for existence", or competition. Only some variants – the most fit – would prevail, changing the heritable traits of the population over time. Natural selection and adaptation may thus seem to rely on competition as a selective force.

In this case, we can effectively trace a close relationship between biological and cultural thinking (Young, 1975; Ghiselin, 1969, pp. 48-49, 59-61; Browne, 1995, pp. 542-543). Victorian England exhibited widespread poverty and great disparities in wealth. Envision Charles Dickens' London: poverty, slums, child labor and grim working conditions, all while others enjoyed a comfortable lifestyle. The social inequities were considered justified (by the franchised, at least) as a "natural" outcome of competition. Thomas Malthus had expressed that view earlier in his 1801 "Essay on Population". He portrayed food as inevitably limited and social competition as unavoidable. When Darwin read that essay in 1838, it helped him crystallize his unfinished thoughts on natural selection. The same essay also prompted Alfred Wallace to discover the same principle. Both Darwin and Wallace transformed Malthus's notion of a social "struggle for existence" into an organic context. Darwin, in particular, seemed deeply impressed by the "logic" of competition:

> One may say there is a force like a hundred thousand wedges trying [to] force every kind of adapted structure into the gaps in the economy of nature, or rather forming gaps by thrusting out weaker ones. (*D Notebook*, pp. 134e-135e; echoed in Darwin, 1858, p. 48; Darwin, 1859, pp. 67, 110)

In closing the *Origin of species*, he rhapsodized:

> From the war of nature, from famine and death, endless forms most beautiful and most wonderful have been, and are being, evolved. (Darwin, 1859, p. 490)

Darwin and Wallace drew on and recontextualized the competitive views of their culture.

The conspicuous cultural origins of the role of competition can guide us in analyzing it critically. Is competition essential to natural selection, as typically portrayed? No. While competition may surely lead to selection, not all selection need be based on competition. Radiation of forms in new adaptive zones, for example – so nicely exemplified by the Galápagos finches – results more from expansion into new niches than from competitive elimination. Likewise, the first organisms to venture onto land flourished more by escaping competition than by "winning" against it. Finding open niches, responding to opportunity and diversifying is a familiar evolutionary theme. Selection can result from differential proliferation, not just competition.

Other times, species seem to have adapted merely by surviving in extreme environments. Some variants were able to tolerate "stressful" habitats – low in water, nutrients, light or other vital resources, or at extreme temperatures, pH, etc. In yet other cases, in frequently disrupted environments, organisms adapt by "being ahead of the competition". They reproduce and disperse again rapidly, rather than compete directly. Life strategies vary widely. At times, natural selection is surely propelled by competition for limited resources. Yet selection also occurs widely without it. Such alternatives, and their meaning for evolutionary processes, may be eclipsed by assumptions about competition.

The perception of selection as crudely selfish, and hence antagonistic among organisms, is also misleading. Many organisms thrive through cooperation. Mutualisms abound. Pollination and seed dispersal symbioses are widely known, but perhaps too often remain in the shadows. Consider sea slugs: soft, slow and vulnerable, the epitomy of non-competitiveness. Some host algae or chloroplasts in their digestive glands, surviving for months without food. In these cases, selection has amplified cooperative strategies. Mutualisms may be intraspecific, as well, exemplified in reciprocal altruism and other forms of sociality. Morality can evolve (Ridley, 1996, de Waal, 1996, Boehm, 1999). When one is open to analyzing the concept of competition in nature critically, its limited scope is readily apparent.

Once again, the problem is not exclusively among biologists, but even more in how biological "knowledge" (or what passes as biological knowledge) circulates among non-biologists. Early supporters of Darwin sometimes inappropriately resituated Darwin's concept into a cultural context. Herbert Spencer and the American capitalists who historian Richard Hofstadter misleadingly called "Social Darwinists," saw in natural selection a "natural" justification for social competition. Contemporary culture seems no different. "Survival of the fittest" rhetoric – or some surrogate about inherent competition – seems to permeate culture – from the World Cup to economic rhetoric, to American Idol and other "reality" television shows. The impression that Darwinism entails social competition is widespread, among both Darwinians and their critics, whether or not they endorse it as ideologically acceptable.

The problem was evident in Darwin's own time – at least given certain perspectives. Socialist Frederich Engels commented on it, virtually defining the naturalizing error, in an 1875 letter:

> The whole Darwinist teaching of the struggle for existence is simply a transference from society to living nature of Hobbes's doctrine of *bellum omnium contra omnes* and of the bourgeois-economic doctrine of competition together with Malthus's theory of population. When this conjurer's trick had been performed… the same theories are transferred back again from organic nature into history and it is now claimed that their validity as eternal *laws* of human society has been proved. The puerility of this procedure is so obvi-

ous that not a word need be said about it (Engels, quoted in Lewontin, Rose & Kamin, 1984, p. 309).

It was not obvious, of course, to those embedded in a culture of competitive ideologies – and who already regarded competition as "normal". The naturalizing error takes hold in cognitive blind-spots.

4 MONSTERS

Let us turn now to yet another case of naturalizing, where cultural concepts are rooted in biological error: developmental anomalies (for references, see Allchin, 2008a). Consider Petrus Gonsalus. Born in 1556 in a remote tribe on Tenerife, he was raised in the court of Henry II in France. As plainly visible here, he was exceptionally hairy. Today, we call his condition hypertrichosis universalis congenita, Ambras type. To his contemporaries he was simply a "monster," an unsual body form, like giants, dwarves or conjoined twins. As his courtly robe indicates, he was also special. Gonsalus and other monsters at that time evoked a widely appreciated sense of wonder. Such puzzling cases also fueled a spirit of investigation and the emergence of modern science, as documented by Lorraine Daston and Katherine Park (Daston & Park, 2001).

For two centuries, monsters remained important cases for understanding nature's patterns and for assessing theories of organismal development. Fontenelle, at the Paris Royal Academy of Sciences, expressed the view well in 1703:

> One commonly regards monsters as jests of nature, but philosophers are quite persuaded that nature does not play, that she always inviolably follows the same rules, and that all her works are, so to speak, equally serious. There may be extraordinary ones among them, but not irregular ones; and it is even often the most extraordinary, which give the most opening to discover the general rules which comprehend all of them. (Daston & Park, 2001, pp. 204-205)

In the early 1800s, Etienne Geoffroy Saint-Hilaire continued the search for those general rules, as exhibited through a proposed "unity of composition". "There is monstrosity", he noted, "but not, by virtue of that, suspension of ordinary laws". Yet in classifying the various developmental variants, Geoffroy also tended to privilege an ideal type. "The normal state of humans may be considered like the abstract being, or generic being", he wrote, "and their different pathological deviations, like the species of this ideal type" (Saint Hilaire, 1822, p. 106, 105, 15). Geoffroy supported Etienne Serres' theory that monsters resulted from various forms of arrested development. "Normal" development had gone awry. Especially as formalized by Geoffroy's son, Isidore Geoffroy Saint Hilaire, the study of monsters, or developmental anomalies, became a science: teratology. At the same time, however, monsters became pathological. The ironic cost of explaining their unusual form was to separate the abnormal from the abnormal.

The development of statistics during the same period further reinforced the concepts of normal and abnormal. Astronomers and geographers had realized that their remeasurements of the same stars or landmarks varied. The variation exhibited what we now commonly recognize as a statistical distribution. But the stars and land had obviously not moved. Some measurements must be "wrong". The desired figure, or ideal, was surely the mean. They thus labeled the variation – today's "bell curve" – as "the Law of Error". Statists found the Law of Error in all kinds of social phenomena, as well. Those regularities became social laws. In the 1830s mathematician Adolphe Quetelet suggested that rather than discuss variable groups, one could just refer instead to the mean, or "average man" (*l'homme moyen*). Statistics thereby further privileged the average, or common, as expressing a law. Statistics seemed to justify a distinction between the "normal" and deviations from it.

With teratology and statistics, monsters changed in the 1800s from wonders, like Gonsalus, to pathological errors, or abnormalities. Consider the case of Joseph Merrick, also known as "the Elephant Man". Merrick exhibited the Proteus syndrome, a genetic condition of excessive bone growth. As visible here, bulbous and pendulous folded tissue on one side was coupled with utterly familiar body forms on the other side. Merrick's movements were uneven. He was a monster, too. But now he evoked disgust rather than wonder. Eventually, Merrick reached the care of physician Frederick Treves and was welcomed in London's elite society. But such protection was deliberate. Treves described how, earlier, "he had been ill-treated and reviled and bespattered with the mud of Disdain" (Howell & Ford, 1980, p. 189). Even under Treves' care, he went hooded and cloaked when traveling in public to avoid incident. Merrick himself never stopped dreaming of being ordinary. Merrick's unusual form did not evoke fascination, but alienation. He "violated" the norms of nature.

The transformation in response to monsters reflects a substantive error. Ordinary and extra-ordinary became "normal" and "abnormal". Anomalies became "abnormalities". Analyzing this shift is challenging because it seems steeped with cultural judgment and values, not facts alone. The term "monstrous" now implies impropriety, not merely unusualness. But to the extent that the normal/abnormal distinction is made and used scientifically, or viewed as objective and validated by science, the error is scientific. Yet the significant effect is surely cultural, reflected in how postures changed from Gonsalus to Merrick. It is the secondary cultural judgment, based on a presumed biological distinction that marks another case of naturalizing.

5 LAWS OF NATURE

The shifting attitudes towards monsters were subtle, but in the context of understanding naturalizing errors, also telling. The difference between anomaly and abnormality is basically the difference between pattern and expectation. Similarly, the error with male-and-female is primarily expecting intersexes, hermaphrodites and polysexes to fit the male/female categories because those categories are, or seem, pre-established. In our competitive culture, who is positioned to recognize competition as anything but an expected foundational principle? The errors, then, are ultimately not just about sex or development or natural selection. They are all about expecting nature to adhere to strict rules. That, in turn, is based on assuming a fundamental and enduring universal order. This expectation itself represents, I contend, yet another naturalizing error: the very concept of laws of nature.

Let me describe just two examples, where laws have been inappropriately idealized. Perhaps the most well known laws in biology are Mendel's Laws. The first is the Law of Segregation: allele pairs separate equally in gametes. Segregation seems grounded in the biology of meiosis. However, in the case of meiotic drive, division is systematically biased, and one chromosome becomes more highly represented in gametes. In other cases, segregator distorter alleles alter the ratio of gametes once formed. Contingent non-disjunction is also well documented. Segregation is not universal and hence not "law-like" in that sense. The second of Mendel's Laws is Independent Assortment: alleles recombine independently. However, genes may be linked on the same chromosome – an exception noted even in introductory textbooks. Mendel's laws have sometimes also included dominance. However, haplosufficiency is exhibited in less than half of human genes. Dominance, too, draws on an inappropriate assumption of either-or competition. Conceptually, dominance is problematic, at best (Allchin, 2005). Exceptions to Mendel's "Laws" are well know to geneticists and other biologists, of course. Yet they continue to be labeled as laws, when they plainly are not. Construing them as inherent natural tendencies, always to be expected, is mistaken. But in textbooks, etc., the lawlike status is preserved and with it, the view of nature as fundamentally lawlike.

Perhaps the second most celebrated biological principle once considered universal and inviolable is the Central Dogma. In 1958 Francis Crick proposed it as a theoretical guidepost: "Once information had passed into protein it cannot get out again." Crick's "central dogma" became expressed in James Watson's 1965 book, *Molecular biology of the gene*, as:

$$\text{DNA} \rightarrow \text{RNA} \rightarrow \text{protein}$$

The formula gained widespread currency as expressing a family of truths beyond doubt. First, cellular functions of information and catalysis (inheritance and metabolism) were differentiated into distinct molecular types. Second, only DNA could self-replicate. Third, information flowed irreversibly from DNA through RNA to protein. All three principles later yielded to exceptions, each recognized by a Nobel prize, a measure perhaps of the depth of the errors. Awards honored the discovery of reverse transcriptase (1975) – where RNA produces DNA; ribozymes (1989) – where RNA can fold on itself and catalyze certain reactions; and prions

(1997) – where proteins can "reproduce", or at least provide the "information" to transform similar proteins into new, disease causing agents. The 2006 prize announcement implied that RNA interference, too, violated the central dogma – by interrupting the "normal" transfer of information from RNA to protein. All these discoveries indicate that belief in the "dogma" of the Central Dogma was misplaced (Allchin, 2008b). There was too much faith, perhaps, that life at a molecular level would be lawlike and that familiar patterns could thus be construed as universal.

Recently, historians have profiled the cultural and religious context that guided the origin of the modern/Western concept of laws of nature (Steinle, 2002). Here, I want only to draw attention to how powerful a hold the concept of laws of nature has on our minds. The very language is highly charged. In human society, laws specify what we *ought* to do. They ensure social order. We tend to interpret laws of nature in the same way, as guaranteeing the natural order. Laws of nature profile how nature *should* act. Once established, *descriptive* laws take on a *prescriptive* character. Pattern becomes expectation. This is how local regularities, or the familiar, or the "normal," become *naturalized*.

6 NATURALIZING AS AN ERROR-TYPE

The ultimate consequences of naturalizing may be discernible now, after several examples, even without much explicit comment. The errors can bias research, of course. But more important, the cognitive prejudices and idealizations subsequently appear culturally as inherent or privileged phenomena of the natural world. Further, those interpretations are construed as facts, ratified by science. But there is no justification. Only a cascade of biased expectations.

The potential cultural consequences are profound. The scientific errors allow mere prejudices to guide ethical and political judgments. So, for example, intersex conditions are not typically valued today as extraordinary, as they once were. Rather, people view them as not fitting nature's categories. They thus work towards "correcting" them with surgery or hormonal therapy. Yet the "problem" is not inherently in the condition. Surgery is not a solution. Rather, the problem is the assessment of abnormality itself – and the assumption that it is established scientifically. Likewise, the role of competition in society escapes scrutiny because it is construed as an inevitable law of nature – or "law of the jungle", perhaps. Yet social competition has political overtones. It disempowers those with fewer resources or those who do not enter society with an already privileged status. Social inequities can thus be perpetuated in part due to an erroneous biological perspective. –Similarly for other cases of naturalizing. Any medical *disorder* – whether developmental, physiological or psychological – idealizes the biology and makes an assumption about "normal" humans: the unstated "order" behind every "dis-order". The rare, the exceptional, or the unfamiliar accordingly reflect unsanctioned disorganization or chaos. Dis-order implicitly implies abandoning order. In general, naturalizing tends to support a view that the way we find things is the way things must be – whether one approves or not. Naturalizing preserves the status quo and homogeneity – the familiar, or frequent, on which the error is based. While scientists can manage errors in the long term, the cultural costs of ill-justified judgments and actions in the short-term are quite real – as are any lingering misconceptions.

While the naturalizing error is a problem, we need not bemoan the inadequacy of science, nor to discredit its ability to secure evidence and interpret it reliably. Rather, if there is a problem, we need to fix it. We need to analyze the error as a first step in being able to remedy it. First, we can characterize thematic similarities in the cases above and then seek appropriate epistemic strategies to address them. This approach is part of a broader effort to analyze error in science and, in particular, to identify characteristic error types. Let me elaborate on this general program.

Researchers frequently talk about "sources of error" in their apparatus or experimental design. The aim is to root out or reduce untrustworthy elements, whether they be theoretical assumptions, malfunctioning instruments, methodological uncertainties, or confounding environmental variables, etc. The program of Error Analytics shares this goal, but vastly expands the scope of the possible sources of error. Errors may also be theoretical or social, for example.

Error Analytics is not unlike lack-of-function studies in biology. It is a classic research strategy (Bechtel & Richardson, 1992).

So, for example, vitamins were discovered through vitamin deficiency diseases, such as scurvy and beriberi; the role of insulin became understood through diabetes. Similarly, errors in science, as deficits and "failures", reveal indirectly the process of ascertaining fact. Each error, once characterized, indicates a method critical to effective science. Analyzing error thereby can contribute to a deeper, more informed philosophy of science.

One can certainly catalog individual errors. But a more powerful analysis finds informative patterns across a number of cases. Deborah Mayo has called these *canonical errors* (Mayo, 1996, 18, 51 n. 17, 150, 453-54). She includes as examples: mistaking chance effects or spurious correlations for genuine regularities, missing a causal factor or using a faulty experimental assumption. In an earlier work I extended this list, arranging errors on a spectrum from those relatively local to direct observations to those relatively derived conceptually and more global in their synthesis of data (Figure 1)(Allchin 2001). This framework of error types provides a scheme for situating and thinking about the suite of naturalizing errors discussed above – which can now be characterized as a significant *error-type*.

So: where do naturalizing errors arise? The deep cultural problems may foster an impression that these errors originate culturally also. Indeed, philosophers generally tend to attribute naturalizing errors to faulty applications of science, not to science itself. They might cite, for example, G.E. Moore's sharp criticisms of how Herbert Spencer based his ideology on his view of evolution as progressive and competitive. Spencer's claims prompted Moore to articulate the Naturalistic Fallacy, the unwarranted derivation of values from nature. This is now a familiar error – in ethics. But the Naturalizing Error, I contend, is different. It is an error in science, not ethics or culture. It is not about extracting values from nature, but rather about inscribing biases into nature where they masquerade as inviolable facts. Many nowadays – echoing Thomas Huxley in Darwin's time – disavow Spencer's ideology, while still believing that competition in nature and human society is inevitable (Brem, Ranney & Schindel, 2003). They escape the Naturalistic Fallacy, but succumb to the naturalizing error. That was Spencer's real error, I claim. When someone believes that competition is essential to adaptation or organic "progress", as

Spencer did, they are interpreting nature itself, not culture. The error is fundamentally scientific.

So, too, for other cases of naturalizing. The error is not in adding a layer of value or disvalue or further interpretation to descriptions of sex or development or recurring patterns. Rather, the error is implicit in how the very categories are framed. They become natural, outside human interpretation and thus beyond the realm of interpretation or justification (see Latour, 1987).

How, then, do naturalizing errors arise? Quite easily. Naturalizing reflects a common cognitive bias: the availability error – that is, giving more significance (or salience) to familiar, or readily available, experiences (Sunderland, 1992, pp. 15-35). That would include foremost one's personal experiences and one's cultural exposure. Living in a culture shaped by explicit competition, or with sharp sexual division of labor, tends to shape ideas consonant with those lived realities.

However, in the cases described here, frequency also matters. Even when scientists are aware of exceptions, the most common or most frequent – the "normal" – may be deemed especially relevant or significant. Frequency may notably contribute to salience. Further, statistical and probabilistic perspectives seem to reinforce (if not precipitate) this style of thinking. What is normal (most common) becomes interpreted as "normal" (sufficiently characteristic of all cases, representative of the whole). Rare cases, however well known, are thus discounted or dismissed. One need not contend conceptually with polysexes, conjoined twins or "dominant negative" alleles. The path to homogeneity begins.

The conceptual slurring is further promoted, I contend, by the concept of laws of nature. Laws of nature, as noted earlier, mark the difference between pattern and expectation, or between observed regularity and fundamental, inviolable order. What is "normal" (experientially or statistically) becomes "natural," or ordained by inherent tendencies of the world. Laws involve idealization. Idealizations may be fruitful to investigation, of course, so long as the idealization does not eclipse the concrete realities – just the case in naturalizing. Shifting from Mendelian models to "laws," or framing common development as an ideal paradigm (to the exclusion of monsters), or male and female as the universal standard (eclipsing intersexes, etc.) transfers any latent bias from the realm of contingent cognitive (human) interpretation to the fabric of nature, where analysis of justification is no longer a concern.

The availability error, statistical perspectives and lawlike conceptualization all reinforce one another in generating naturalizing errors. They foster similar conceptual elisions, whether from convenient example to generalization, sample to universal conclusion, or pattern to idealized law. Familiar (but contingent) phenomena thereby become misleading emblems of essentialized Nature. Moreover, statistical and lawlike thinking, ironically, seem to naturalize the cognitive bias itself, and thus tend to conceal its role. Biased naturalized concepts emerge with the imprimatur of science.

There is more to naturalizing errors, however. While they originate with scientists, their importance lies primarily beyond scientific discourse. Concepts radiate from the well informed, who may be aware of any exceptions and limitations, to the larger culture, where scientific "laws" and concepts are rendered absolute. Here, one needs to attend to the demography of knowledge. The question is not just what is known, but also who knows it – or what is known by different persons in different positions (Goldman, 1999). The error-type distinctively crosses epistemic zones. One must thus additionally consider how *what counts* as biological knowledge is established *in cultural contexts* (Toumey, etc.). In this case, the naturalizing error involves inscribing bias into nature *and* legitimzing those scientific views (culturally) as inviolable facts of nature.

Here, again, the role of laws of nature as a concept seems especially significant. Scientifically, naturalized laws may merely blinker investigative opportunities. Culturally, the belief in laws of nature gives scientific concepts their caché and places them beyond the need for analysis. That is deeper than just inherent trust in science as a reliable enterprise. "You can't change the laws of nature" means that those scientific concepts, once established, reflect invariable, exceptionless features of the world. That is much stronger than interpretations of models or syndromes. Scientists, of course, often nurture this view. Many believe that science should be simplified or truncated for non-scientists to understand it. Laws are presented without their qualifications (their boundary conditions, their ceteris paribus clauses, etc.); concepts, without their exceptions or complexities. The cost of such simplification, however, may be the habituated belief that nature itself is indeed simple. Thus, no one thinks to question such simple concepts as male-and-female, normal development or a single cause for natural selection.

In summary, naturalizing as an error-type is a conceptual error, a form of unchecked cognitive bias amplifying the familiar (whether culturally standard or observationally frequent). But the error is compounded, as many errors are, by being passed "downstream" – again, unchecked – through longer communication networks into cultural settings (Latour, 1987), nurtured by belief in natural order and simple laws of nature.

7 EPISTEMIC STRATEGIES

How, then, are naturalizing errors found and fixed? As a cognitive bias, naturalizing is best regulated by alternative or "critical" perspectives. Ideally, those might arise with imagination and active self-criticism. A full taxonomy of error-types might well serve as a template or guide. But cognitive bias is a problem largely because it tends to escape such checks. We may be reminded that, historically, sexism and racism receded in scientific discourse only when women and different ethinic groups became more fully represented in the scientific community (Fee, 1979; Barkan, 1992). Epistemically, diversity of participants fosters diversity of perspective (in particular ways), which optimally leads to fruitful critical discourse about the evidence or its completeness – social epistemic methods nicely articulated by Helen Longino (1990) and Miriam Solomon (2001), among others. Ultimately, the naturalizing error is prospectively regulated by diversity in a scientific community, diverse especially with regards to the concepts being developed, and where "dissenting" standpoints are also acknowledged and engaged responsibly. For example, discourse on male and female should include at least some intersex individuals – and such interchange has occurred recently with clinical health professionals. Evolutionary biologists should at least heed the contributions of socialists or anarchists, such as Petr Kropotkin, frequently dismissed as renegades or crackpots. Medical concepts may profit from critique by patients with "disorders"; academic biology may profit, ironically, from the perspective of non-intellectuals; etc. The naturalizing error illustrates well to philosophers and sociologists the importance of thinking through social epistemology more fully.

To be complete, however, a remedy for naturalizing errors also needs to address the central and pervasive role of the concept of laws of nature. Is this a concept to be remedied at all?, some may surely ask. If it is an error, it is certainly rooted very deeply. Still – setting aside debates about the frequency or special place of laws in biology (Beatty, Rosenberg, Dupre, etc.) – we can consider the concept of laws across *all* the scientific disciplines as its own, possibly gendered, cultural bias (Allchin 2006b, 2007c). Indeed, historians and philosophers of science have already begun to sketch the alternative. Focusing on experiment and scientific practice, they emphasize the role of models and experimental paradigms instead of universal theories, and analogical reasoning rather than hierarchical deductive logic (Kuhn, 1970; Giere, 1999; Wimsatt, 2006). Eventually, we may come to abandon such icons as Boyle's law, and discuss instead the behavior of air in Boyle's J-tube, with its contingent relevance to other similar apparatus. Mendel's Laws may gracefully yield to an equally informative, but more carefully circumscribed Mendelian model. The Central Dogma can be become an instructive historical artifact, exposing the possible scope of error from widely adopted assumptions. Overhauling the concept of laws of nature may require a dramatically revised worldview, as re-envisioned, for example, by Nancy Cartwright (Cartwright, 1999). In this context, historians and philosophers of science (especially of biology) have an important role in profiling the methodological norms that foster naturalizing errors.

Having sketched strategies for regulating naturalizing errors as an error-type, we may return to the more concrete question of realizing such prospective solutions in practice. Situating naturalizing errors in the spectrum of error types helps underscore the role of professional biologists as producers and stewards of public knowledge. Errors in science flow "downstream" into cultural contexts, where the errors persist and their consequences unfold, sometimes quite dramatically. Within biology proper, naturalizing errors may seem relatively insignificant. Exceptions and qualifications may be well known in the fields where they are relevant. – And any remaining error seems easily subject to further research in due time. Yet the problem of naturalizing is hybrid: it is the downstream cultural effects that matter most. There, the harm from misinformation cannot afford the luxury of academic forbearance. Naturalizing is a scientific error, and scientists are responsible for addressing it, especially in communicating science to the public. Of course, biologists can become better informed about the potential for naturalizing errors by historians, philosophers and sociologists of biology.

Finally, perhaps the most important locus for addressing naturalizing errors is in the science classroom. There, students learn the view of nature apparently sanctioned by science, with all its aura of authority. Textbooks are not just tools for understanding concepts. They become an official "voice" of the nature of science. Textbooks writers, often scientists themselves, need to be especially aware of the cultural dimensions of what they present. In biology, exceptions ironically need to be the "norm". Students need to learn about intersexes, polysexes, developmental variation, genetic diversity, non-competitive evolution and, throughout, the nature of scientific models and methods, their virtues and limits. Fortunately for teachers, perhaps, all the complexities and exceptions in biology fascinate and engage students. Ideally, they also learn about cases of historical error in science, as a cautionary lesson about how science actually works in practice. Here again, historians and philosophers of biology have a special role. They can educate educators. Ideally, history and philosophy of science and science education are close allies. It is certainly a tribute to Brazil that its science education standards so prominently include history and nature of science, and that collaborations between HPS and education thrives. Brazil may well be leading the way in the science education of the future.

My ultimate hope, then, is that through education and awareness, boy and girl, man and woman, male and female, and other culturally biased concepts of nature will seem a little less "natural". Through HPS collaborations with biologists and biology educators alike, we will be more effectively equipped to address, and thereby minimize, naturalizing as an error-type in biology.

TAXONOMY OF ERROR TYPES

DERIVED (GLOBAL) ◄)))))))))))))))))))))))))))))► LOCAL

Material

- improper materials (impure sample, contaminated culture)
- improper procedure (experimental protocol violated, poor technical skill)
- perturbation of phenomenon by observer (placebo effect)
- failure to differentiate similar phenomenon through controlled conditions

Observational

- insufficient controls to establish domain of data or observations
- incomplete theory of observation (instrument/protocol not understood)
- observer perceptual bias ("theory-laden" observation, need for double-blind)
- sampling error (statistical rarity, weak significance level cutoff or other probablistic factors)

Conceptual

- flaw in reasoning (includes simple computational error, logical fallacies, mistaking correlation for causation, incomplete evidence)
- inappropriate statistical model
- inappropriate specification of model from theory
- misspecified assumptions or boundary conditions
- theoretical scope (domain) over/undergeneralized
- incomplete theory, lack of alternative explanations (limited creativity)
- **cognitive biases** (misplaced salience, normalizing)
- theory-based cognitive bias, entrenchment
- unchecked sociocultural biases (gender, ethnicity, economic class, etc.)

Discursive

- communication failures: incomplete reporting, obscure publication, translation hurdles, patchy citation/search system
- **naturalizing**
- mistaken credibility judgments (Matthew effect, halo effect) / fraud
- breakdown of systems for credentialing scientific expertise
- public misconception of scientific results and misunderstanding of science (poor science education, poor science journalism, etc.)

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